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Sindy cherry tomato: A low potassium (K) demanding, high-quality and highly productive cultivar

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Abstract

Potassium (K) is one of the most abundant nutrient and has the greatest influence on fruit quality as it regulates the synthesis and translocation of photoassimilates in plants. K deficiency in tomato plants can compromise the quality and flavor of fruits. Thus, the objective of this work was to evaluate the effect of K doses on the production and quality of cherry tomato fruits in a hydroponic system. We cultivated the cherry tomato Hybrid Sindy for 120 days, from June to October, in an expanded clay sub irrigation system. The experiment was arranged in a completely randomized design with four replicates. The treatments consisted of increasing concentrations of K (6, 8, 10 and 12 mmol L^{-1}) in the nutrient solution provided during the fructification period. It was evaluated production, mean weight of fruits and bunch, total soluble solids contents, titratable acidity, pH, and contents of lycopene, β-carotene, and *a* chlorophyll. The contents of nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, copper, boron, iron, zinc, and manganese were also determined in the fruits and in the third leaf above the fourth fruit bunch. Six mmol L^{-1} of K in the nutrient solution was enough to ensure the production and quality of the Sindy hybrid cherry tomato. Nevertheless, higher K doses improved the contents of the bioactive compounds lycopene and β -carotene in the fruits.

Keywords: *Solanum lycopersicum* L.; mineral nutrition; nutrient solution; subirrigation; productivity.
Abbreviations: N - nitrogen; Zn - zinc; Cu - copper; Fe - iron; B - boron; Mo - molybdenum; HCl - hydrochloric acid; NaOH - sodium hydroxide; TSS - total soluble solids; TA - titratable acidity; DAT - days after transplanting.

Introduction

Tomato is one of the most fertilization demanding species. The average of nutrient contents in plant tissues may vary depending on the stage of development, cultivar, temperature, soil, luminosity, relative humidity, and management (Alvarenga, 2013). The yield and fruit quality of tomato are severely influenced by mineral nutrition (Sasaki and Seno, 1994), as both lack or excess of nutrients compromises the plant metabolism (Alvarenga, 2013).

Potassium (K) is one of the nutrients most required by the tomato plants, as it regulates synthesis reactions, and consequently has great influence on fruit quality (Taiz and Zeiger, 2013; Alvarenga, 2013). It also participates in the translocation of photoassimilates, cell elongation, and enzymatic reactions related to photosynthesis, respiration, synthesis of starch, proteins, and lignin (Malavolta et al., 1997, Barreto and Bezerra Neto 2000, Marenco and Lopes, 2005). Thus, because of the imbalance in enzymatic metabolism, K-deficient plants are impaired in the synthesis and translocation of carbohydrates to the fruits, compromising its fruit quality, regarding appearance, flavor, texture, and nutritive value (Marschner, 2011).

The content of sugar, acids, and volatile compounds determines the tomato flavor (Krumbein and Auerswald, 1998), and the best fruits are those with low titratable acidity, high content of total sugars and soluble solids, and intermediate content of volatile compounds (Tando et al., 2003). K fertilization can favor fruit production, ensuring quality through the production of fruits with a more reddish color and more homogeneous pulp (Alvarenga, 2013).

Lycopene is one of the carotenoid pigments found in high concentration in tomato, responsible for the red color of fruits and has an important antioxidant function in human nutrition (Shami and Moreira, 2004). Moreover, the presence of lycopene in the diet is related to the reduction of certain types of cancer like prostate cancer (Giovannucci, 1999; Costa and Matias, 2014). It also has been related to reduction of heart attack risk (Carvalho et al., 2006). Besides, tomato has high content of carotenoids, and β-carotene is associated with protection against heart disease and cancer (Carvalho et al., 2006), also having antioxidant and immunomodulatory actions (Rodriguez-Amaya, 2002). Cherry tomatoes is a high yield group that nowadays has been increasing in consumers' preference and farmers interest, since its cultivation may be a way of diversifying the tomato crops and improve farmers' profits. Although tomato being a very studied crop, there is a lack of information about nutritional requirements, and about how nutrient management can improve production and fruit quality of the new cherry tomato varieties, specially under hydroponic cultivation. Thus, the objective of this study was to evaluate the production and quality of cherry tomato grown in hydroponic sub-irrigation system under increasing K doses.

Results and Discussion

Mean weight of fruits and bunches and productivity

The proportion of fruits in each diameter class, and mean weight of fruit and bunches, were not significantly affected by the K doses studied. These results may be due to the lower K nutritional requirement of the variety of cherry tomato used in this study, since Fernandes et al. (2002) reported good development and production of the long-life tomato Alambra cultivated in similar conditions with 8.6 mmol L^{-1} of K. The cultivars of cherry tomato AsHiari grafted on cv. Maxifort rootstock also showed that the fertilization with different doses of K did not affect the number of fruits per plant but promoted the increase in K concentration and decreased the fresh weight of commercial fruit production (Constán-Aguilar et al., 2015).Some authors stated that, although tomatoes' demand for K been high, responses to the application of this nutrient to the soil are not frequent (Boaretto et al., 1983; Takahashi, 1993). However, in hydroponics, positive effects would be expected, since in this system the establishment of adequate concentrations of nutrients and their wide availability are closely related to the satisfactory growth and development of plants (Taiz and Zeiger, 2013). The cultivars Cereja 261, San Marzano (Italian type), Santa Clara (salad type), and the Cherry Chipano hybrid, growing under N and K ratios, showed higher yield and fruit quality in hydroponic cultivation (204 mg L^{-1} of K) than in fertigated system (450 kg ha^{-1} of K) (Genuncio et al., 2010).In the present study, the average yield per plant was 4,001.99 g, which means to 125.45 t ha^{-1}, considering 31,347 plants per hectare, in a 120-day crop cycle. Although K doses in the nutrient solution didn’t result in significant differences among treatments this yield was higher than those reported in the literature, for both the salad group and the cherry group. The average fruit yield of the long-life tomato cv. Alambra cultivated in the field and with two stems was 100 t ha^{-1} (Suzuki et al., 2010). The hybrid Super-Sweet cultivated in organic system and conducted with two stems showed total yield of 11.63 t ha^{-1} (Azevedo, 2006). Fruit production of five cultivars of cherry-type tomatoes ranged from 2.45 to 3.35 kg per plant (Machado et al., 2003), which, extrapolating to the same population of plants used in this work, corresponds to yields from 76.8 to 105.01 t ha^{-1}, below the production achieved in this study. Abrahão et al. (2011) found that cv. Sweet Million showed higher production than Sweet Grape (1.69 kg per plant – 52.98 t in 120 days) under different K:Ca:Mg ratios in the nutrient solution.The mean fruit weight and the mean weight of the bunches showed no significant differences regarding to the K concentrations in the nutrient solution, and the same result was found for the interaction of K dose and bunch position. However, these variables were influenced by the isolated effect of the bunch position (Fig. 1). There was a marked decrease in the mean weight of fruit from the first to the fourth bunch. It can be highlighted that the fruit production in the fourth bunch was more delayed compared with the other bunches, that is, the plants were near 90 days after transplanting at the onset of this bunch. One possible reason to this is that at this time, the plant demand of water, nutrient and photoassimilates was higher, and this fact affected the partition of photoassimilates among the plant organs. Also, the nutrient solution could be imbalanced at this time, since nutrient re-additions were done by measuring the electrical conductivity, assuming up to 30% depletion, without consider the contents of nutrients individually. Watthier et al. (2008) evaluated the yield of cherry tomato cv. Vermelho, Blue Line (Topseed Garden®) as a function of the floral bunch position and the nutrient concentration in the nutrient solution. They found that the bunch position had no influence on the mean fruit weight, and bunch weight.From the first to the fourth bunch produced by the plants, the fruit weight varied from 16 to 20 g and the number of fruits per bunch ranged from 20 to 40. These results are higher than the reports in the literature. Fruits of cv. Sweet Grape grown under different K:Ca:Mg ratios weighed on average 9 g (Abrahão et al., 2011). In plants of cv. Cereja Vermelho under different saline concentrations on the nutrient solution the number of fruits per bunch and the mean weight of the fruit were, on average, 18.58 and 11.94 g, respectively (Watthier et al., 2008).

Fruit quality

The mean values of total soluble solids (TSS), titratable acidity (TA), pH and TSS/TA observed were 7.45 (^{o} Brix); 0.43 (% of citric acid); 4.1 and 17.45 respectively, and were not affected by increasing doses of K. Despite of that, in the present study, we found TSS values higher than the reported for tomato by many authors in the literature (Gusmão et al., 2000; Feltrin et al., 2005; Blanco and Folegatti, 2008). It can be highlighted that TSS is one of the features that provide tomato flavor and establishes quality of the product. Regarding the variables related to fruit quality, only the concentrations of chlorophyll *a*, lycopene and β-carotene were influenced by increasing doses of K (Fig. 2). In the first, bunch the concentrations of chlorophyll *a* increased with higher K doses, whereas in the fourth bunch the chlorophyll content decreased with increasing K doses. Lycopene was influenced by the K doses in the first bunch, reaching 83.75 µg 100 mL^{-1}, but there was no effect on the fourth bunch. Some studies have demonstrated a relation between the increased K concentration and lycopene content of cherry tomato (Constán-Aguilar et al., 2014). Taber et al. (2008) studied the effect of K fertilization on the content of lycopene in tomato fruits and found different responses among cultivars. Cv. Spring Mountain presented no effect of K doses in lycopene contents, while cv. Fla 8153, that contained 9.5 mg kg^{-1} more lycopene than the former, showed an increase of 21.7% of its content of lycopene with the highest K dose (372 kg ha^{-1}). Already Ramírez et al. (2009), working in greenhouse, with the hybrid tomato 'Gabriela', observed a positive effect of the increase of K doses in the nutrient solution on the content of lycopene and β-carotene in the fruits. These authors stated that these features can be used as indicators of intrinsic quality, based on analytic and sensorial qualities (Ramírez et al., 2012). β-carotene was also significantly increased by the doses of K only in the first bunch (Fig. 2C). In the fourth bunch the trend was the opposite; in this case the highest concentration of β-carotene was found at the lowest dose of

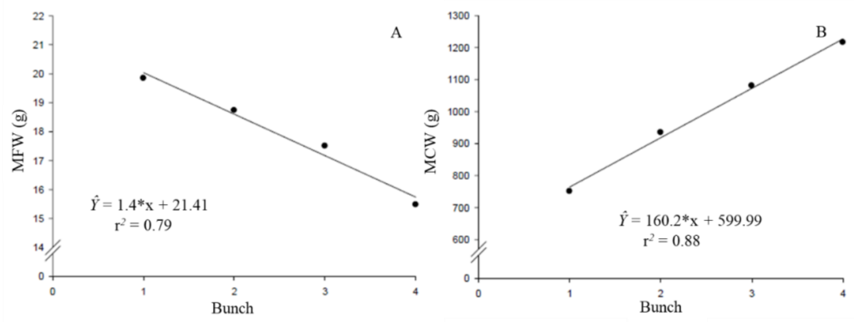

Fig 1. Mean fruit weight (MFW) (A) and mean bunch weight (MCW) (B) as a function of bunch position (1, 2, 3, 4) in Sindy hybrid cherry tomato grown in hydroponic subirrigation system. * Significant at 5% by t-test.

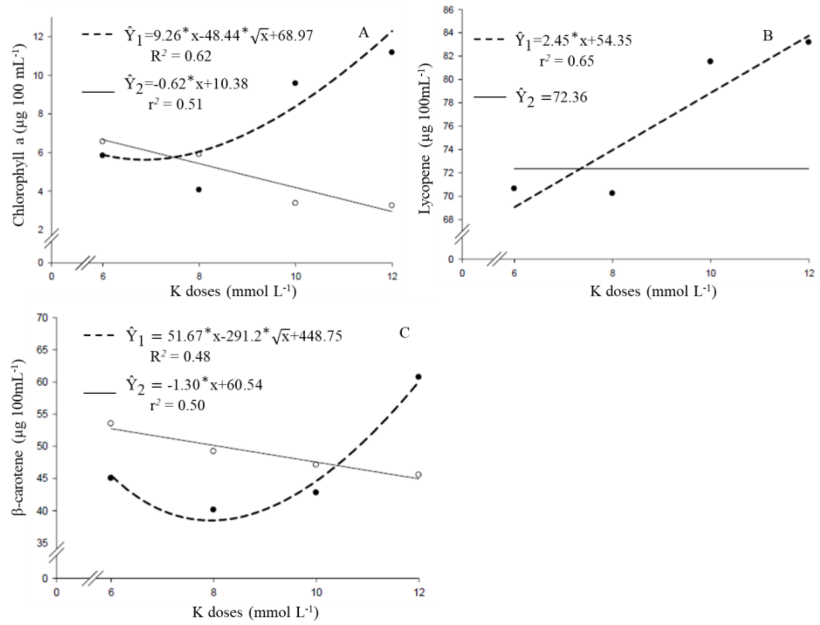

Fig 2. Contents of chlorophyll a (A), lycopene (B) and β-carotene (C) in fruits of the first bunch (Ŷ1) and in fruits of the fourth bunch (Ŷ2) of Sindy hybrid cherry tomato grown in hydroponic subirrigation system, under increasing K doses.
* Significant at 5% by t-test.

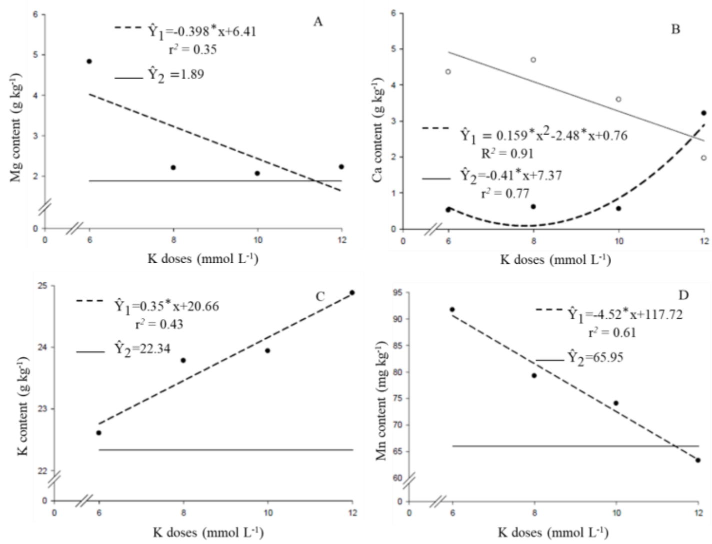

Fig 3. Concentration of the nutrients Mg (A), Ca (B), K (C) and Mn (D) in fruits of the first bunch (Ŷ1) and in fruits of the fourth bunch (Ŷ2) of Sindy hybrid cherry tomato grown in hydroponic subirrigation system, under increasing K doses.
*Significant at 5% by t-test.

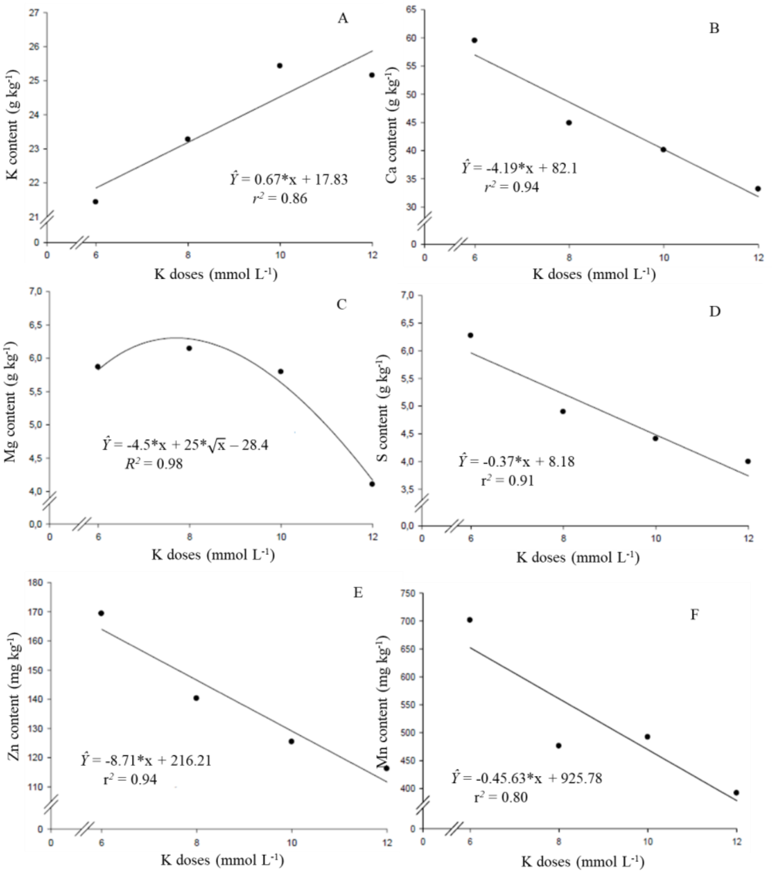

Fig 4. Macro K (A), Ca (B), Mg (C), S (D) and micronutrients Zn (E), Mn (F) contents in the third leaf above the fourth bunch of Sin dy hybrid cherry tomato, grown in hydroponic subirrigation system, under increasing K doses.
* Significant at 5% by the t test.

K. Similar result was found by Constán-Aguilar et al. (2015) in cherry tomato fruit, since they observed that β-carotene decrease with the increase of K doses along the fruit sampling period. For fruit samplings, 20 weeks after transplanting, as K increased, the concentration of β-carotene increased. For samples at 24 weeks after transplanting, the trend was the opposite. Like in our work, in such case, the highest concentration of β-carotene was found at the lowest dose of K.

The directly proportional relation between the increase in the K dose and the greater concentration of chlorophyll *a*, lycopene and β-carotene was found only in the first bunch sampling. The different result obtained for the fourth bunch could reflect the enhancement of cation competition promoted by the high K doses along the culture cycle. The relatively low demand of nutrients early in the culture cycle and onset of the first bunch probably counteracted the negative effect of high K doses over the absorption of another cations, like Ca, Mg and Mn that may be involved in chlorophyll and carotenoid synthesis. It is known the participation of Mg in the chlorophyll molecule. Feltrin et al. (2005), evaluating the productivity and fruit quality of the Sweet Million, Rocio and Densus cherry tomato cultivars fertigated with K chloride and K sulfate, found that with respect to quality characteristics, K sources influenced only the pH.

Concentration of nutrients in fruits

The concentrations of N, S, Cu, Fe and Zn nutrients were not affected by the K doses in the fruits independent of the analyzed bunch (Data not presented). Contents of the nutrients K, Mg and Mn in the fruits of the first bunch and Ca in the first and fourth bunches were influenced by the K doses (Fig. 3). The concentration of Mg decreased with increasing K doses, reaching 1.64 g kg^{-1} at the highest K dose (12 mmol L^{-1}). The Ca content in the fruits of the first bunch increased with the increase in K doses but decreased linearly in the fruits of the fourth bunch. The K content in fruits showed a linear adjustment with the increase in K doses, while the Mn content decreased. Such findings are in accordance with the fact that the maintenance of the ionic balance or electroneutrality in plants are related to the competitive interaction between the cations Ca^{2+}, Mg^{2+} and K^+ (Dibb and Thompson JR, 1985). This competition indicates that the accumulation of K over time impaired the absorption of other cations, mainly Ca. However, even their concentration decreasing with the increase of K, the plants were not deficient in these cations. The increase in K concentration in fruits indicates that this nutrient may have directly influenced fruit metabolism, due to the changes observed in the quality characteristics evaluated.

Concentration of nutrients in index leaves

The concentration of the nutrients N, Cu and Fe in the third leaf above the fourth bunch were not affected by the increase of the K doses (data not presented). Besides that, K doses on the nutrient solution used in the fructification stage influenced the nutritional status of the plants, evaluated by their contents in the third fully expanded leaf above the fourth bunch. The K content increased linearly with the increasing K dose in nutrient solution, while Ca, Mg, S, Zn and Mn concentration decreased (Fig. 4). Regarding Ca, Mg, Zn and Mn it is justified by the well-known phenomenon named cation competition. In this work the increase of K content in the plant inhibited Ca, Mg Zn and Mn uptake. Relative to Ca and Mg, the lack of these nutrients contributes to poor lamella formation, imbalance of plasma membrane function, and low ATP formation; and Zn takes part in the integrity and functionality of cell membranes (Marschner, 2011; Malavolta, 2006).

Figure 4A shows that the K concentration in the leaves was lower than those reported in the literature, from 30 to 50 g kg^{-1}; but Ca, Zn, and Mn were above the sufficiency range reported (13 to 38 g kg^{-1}; 60 to 70 mg kg^{-1}; and 50 to 250 mg kg^{-1}, respectively). Mg and S remained within the sufficiency range reported (4 to 6 g kg^{-1}). However, we can consider that the critical levels may vary with species and cultivars (Malavolta et al., 1997; Silva and Giordano, 2000; Silva et al., 2001; Fernandes et al., 2002; Fontes, 2004). Interestingly, the differences observed in nutrient content had no influence on fruit production. Besides, nutrient content depends on several factors such as nutrient concentration in the growing medium, planting time, plant age, climatic conditions, and the interactions between nutrients (Carvalho et al., 2004; Lima et al., 2011).

Materials and Methods

Plant materials

The study was carried out using a subrrigation hydroponic system, in a greenhouse of the Department of Fitotecnia, Federal University of Viçosa (UFV), Viçosa, MG, Brazil, during a period of 120 days from June to October with the cherry tomato Hybrid Sindy.

Treatments

The plants were submitted to four K doses: 6, 8, 10, and 12 mmol L^{-1} in the nutrient solution during the reproductive phase. The experimental units consisted of troughs of fiber cement waterproofed with asphalt paint, 0.85 m wide in the upper part; 0.60 m wide at the base; 0.20 m high, and 3.75 m long. The troughs were filled with expanded clay, and the nutrient solution was supplied by subirrigation, pumped from four containers with 1000 L capacity. Each container provided the nutrient solution corresponding to each treatment, that means, to four troughs randomized in the greenhouse, which corresponded to the replications.

Experimental design and system management

The experiment was performed in a completely randomized design with four treatments and four repetitions. Seedlings with 3-5 true leaves, produced in phenolic foam with 5 x 5 x 3.8 cm, were transplanted to the troughs, at the spacing of 0.3 m between plants and one row per experimental unit, totalizing 10 plants per plot. The plants were cultivated in vegetative growth solution with 100% of ionic strength containing: 8; 2; 4; 2; 1; and 1 mmol L^{-1} of N, P, K, Ca, Mg, S, and 35; 19; 21; 4; 0.9; and 0.7 µmol L^{-1} of Fe, Mn, B, Zn, Cu and Mo, respectively. After emission of the first bunch, the nutrient solution was changed to the fruiting formulation containing: 12; 3; 3; 1.5; 1.5 mmol L^{-1} of N, P, Ca, Mg, S, and 59; 20; 25; 4; 1.3; and 0.7 µmol L^{-1} Fe, Mn, B, Zn, Cu and Mo, respectively, and K doses according to the treatments. Both nutrient solutions were based on Fernandes et al. (2002). The volume and the pH of the solution were checked in a daily base. Every day the volume was replenished with water up to the initial volume of 1000 L in each container and the solution pH was adjusted to 5.5 - 6.5 with HCl or NaOH. Periodic additions of nutrients were performed when the electrical conductivity of the nutrient solution depleted to 70% compared to the value measured at the beginning of the experiment. The plants were conducted with two stems, tied with strings in a metallic wire stretched 1,5 m above the plant, and have had their terminal buds pruned three leaves above the fourth fruit bunch. The fruits were also pruned leaving an average of 20 fruits per bunch not branched. The branched bunches were left with 12 fruits per branch. Pruning took place during all the experiment to control the number of fruits and removal of side shoots.

Traits measured

The harvest was done when basal fruits of each bunch were fully red. The fruits were then detached from the bunch, separated into classes of diameter (> 20, 20-25, 25-30, 30-35, 35-40 and> 40 mm) (Fernandes et al., 2007) and weighed. It was recorded the data of proportion of fruits in each class, fruit weight per plant, mean weight of each fruit and mean weight of bunches. After harvest, samples of fruit pulp of each bunch were homogenized using a domestic mixer and the following characteristics were evaluated: a) TSS content: determined by the direct reading with a digital refractometer; b) TA: as described by Carvalho et al. (1990) and expressed as % of citric acid in the pulp; c) pH: direct reading in pH meter; d) TSS/TA: determined by dividing soluble solids content by titratable acidity; e) contents of lycopene, β-carotene, and chlorophyll *a* determined by spectrophotometry, according to Nagata and Yamashita (1992). At full flowering (50 DAT), the third leaf above the fourth fruit bunch was harvested to determine the concentration of nutrients and assess plant nutritional status. Samples of fruits and leaves were dried in a forced air circulation oven from 65 to 70ºC to constant weight. The dried samples were weighed, ground, sieved, and digested in sulfuric acid for N analysis by the micro-Kjeldahl method. Other samples were subjected to nitric-perchloric digestion and in these extracts K content was determined by flame photometry; S by turbidimetry, and Ca, Mg, Cu, Fe, Mn and Zn by atomic absorption spectrophotometry.

Statistical analysis

The data obtained were subjected to variance and regression analysis. The regression models were chosen according of biological meaning and the significance of the regression coefficients using t-test at 5% probability. For the mean weight of fruits, and mean weight of bunches, the data was arranged in a split-plot design with K dose assigned to the main plot and bunch position (1, 2, 3 and 4) assigned to the subplot. The variables of quality were also arranged in the split-plot design, with K doses assigned to the plot, and position of the bunches (first and fourth) assigned to the subplot. Likewise, according to data significance, the regression analysis was used for K doses within bunch position.

Conclusion

The cherry type tomato cv Sindy demonstrated to be low K demanding, achieving high production and good quality with 6 mmol L^{-1} of K in the fructification nutrient solution. Nevertheless, high K doses improved the contents of the bioactive compounds lycopene and β-carotene in the fruits. The increase of the K dose up to 12 mmol L^{-1} of K in the fructification nutrient solution also reduced the contents of Ca, Mg, S and Zn in the diagnostic leaves, but without reaching the deficient level and compromise the plant production.

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